NAVOCEANO-NPS Thesis Program on Littoral Warfare Oceanography

Dr. Peter Chu, Professor of Oceanography, NPS
Steven D. Haeger, Director, Department of Ocean Modeling, NAVOCEANO

1. Background

Over the decade, there has been a rapid re-focusing of the Navy's resources to support joint littoral warfare through several joint, naval, and marine corps white papers. Specifically, the Naval Oceanographic Office (NAVOCEANO), Naval Research Laboratory (NRL), and Naval Postgraduate School (NPS) are implementing the ocean prediction system in several littoral basins; these systems include not only the models per se, but historical and real-time data. Historical data is required to understand the basic physics of the oceanography/meteorology in order to properly optimize a model and to determine the forcing function for a specific basin. NAVOCEANO also performs direct analysis on data to construct products in the Warfare Support Center (WSC). NPS recently established the Naval Ocean Analysis and Prediction (NOAP) Lab in the oceanography department. One of its charters is to study: (1) what is the measure of effectiveness of environmental knowledge? (2) what are environmental effects on littoral warfare, and (3) to educate the Naval officers on these effects. Such quantitative analyses offer a means to optimize war fighting requirements and technical capabilities of new weapon systems. As the competition for resources intensifies, the Department of the Navy turns increasingly to such analyses for guidance on investment decisions. The lack of such analyses for meteorological and oceanography (METOC) support could place the Navy's METOC community at a disadvantage in the competition for resources. Major investments such as a next-generation Major Shared Resource Center for METOC support need the justification provided by these analyses.

The major threats in the littoral are diesel submarines and sea mines. The combination of improvements in noise reducing technology and the development of Air Independent Propulsion (AIP) technology have made diesel submarines very difficult to detect in both the littoral and blue waters. After a weapon platform has detected its targets, the sensors on torpedoes designed for blue water operations are not designed to acquire a target in a reverberation-crippling environment.

Even though naval mines are not as sophisticated a weapons system as torpedoes, they have been number one cause of U.S. Naval casualties since the end of World War II. Naval mines are a relatively cheap weapons system that can be easily obtained by any nation in mass quantities. In addition, naval mines do not require an expensive and sophisticated weapons platform for deployment; they can be easily deployed by small watercraft. There are several types of mines, which are classified by their mode of activation and their placement in the water column. The simplest of naval mines are floating contact mines. These mines are usually detected visually and cleared by minesweepers and Explosive Ordnance Disposal (EOD) units.

Several major issues in Mine Warfare (MIW) are mine impact burial, mine hunting, and littoral oceanography for MIW, such as the East Asian marginal seas (i.e., the Sea of Japan, the Yellow Sea, the East China Sea, and the South China Sea). Dr. Peter Chu and his students at the NPS Oceanography Department, have been working in these areas for several years with the sponsorship from NAVOCEANO and ONR. During the past few years, they performed several mine impact burial experiments in the Monterey Bay (real-time environment) using a dummy mine and in the laboratory using model mines. They tested the current Mine Impact Burial Model (IMPACT25/28) and found several severe weaknesses of model. They tested the Navy's Comprehensive Acoustic Simulation System/Gaussian Ray Bundle (CASS/GRAB) model in the Yellow Sea scenario with several NAVOCEANO's environmental datasets. They analyzed the variability of the East Asian marginal seas for MIW.

NPS, NAVOCEANO, and students themselves have all benefited from this NAVOCEAN-NPS thesis program. NPS gets a strong Navy relevant research program, the NPS students get the best training available for their future job, and they will be more supportive of NAVOCEANO after leaving NPS.

2. Mine Impact Burial Prediction

Two approaches are available to predict mine impact burial: empirical and dynamical. The Naval Oceanographic Office (NAVO) used the empirical approach to build a bottom sedimentation data set and to group more than 200 types of sedimentation into 5 categories for the impact burial prediction. The Coastal System Station (CSS) took the dynamical approach to develop the impact burial prediction model (IBPM) (Arnone and Bowen, 1980). The IBPM was updated by many investigators (Satkowiak,1987, 1988; Hurst and Murdoch (1992); Mulheran (1993); Taber (1999); Chu et al. (2000, 2002a,b,c) since then. Despite the nine variations of the IBPM currently available, they all use the same physics to predict the vertical free-fall time history of a mine (cylindrical or other shapes) as it passes through air, air-water cavity, water, water-sediment cavity, marine sediment phases, and the depth of burial on impact with the sediment (Figure 1). The environmental parameters are taken as constants when running the IBPM model. Sensitivity studies (Taber 1999; Chu et al. 2000) show that sediment density and shear strength are important for the impact burial prediction.

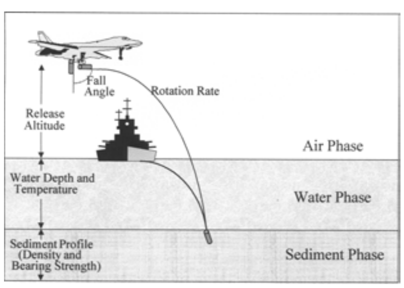

Figure 1. The trajectory of a mine as it falls through three phases: air, water , and sediment. Labels on the left are parameters used by IBPM to calculate velocity, Attitude, and burial depth of the mine.

With the sponsorship from the Office of Naval Research and the Naval Oceanographic Office, two approaches were adopted (experimental and modeling) to develop a comprehensive Mine Impact Burial Prediction Model.

(A) Experimental Approach: A series of mine drop experiments with different sizes of model mines were conducted at NPS and Naval Surface Warfare Center to obtain a complete dataset for depicting the mine movement in the water column:

Analysis of the data collected from the Mine Impact Burial Experiment (MIBEX). This experiment was designed to collect synchronous mine impact burial and environmental data. The experiment was conducted on May 23, 2000 at the site of the Monterey Inner Shelf Observatory (MISO) off of Del Monte Beach in Monterey Bay (Smith 2000). The model mine is a 55 gallon drum filled with sand to give it a uniform density. During the experiment, 17 gravity cores were obtained. The oceanic environemental paramteres were recorded at MISO. The burial depth was measured by the divers. The mine impact and environmental (water column and sediment) data were analyzed in FY01.

Mine Drop Experiment (MIDEX) at the NPS swimming pool. MIDEX basically consisted of dropping each of three right cylinders into the water where each drop was recorded underwater from two viewpoints. The controlled parameters for each drop were: center of mass position (COM), initial velocity (V_{init}), drop angle and the ratio of mine's length to diameter. Figure 2 depicts the overall setup.

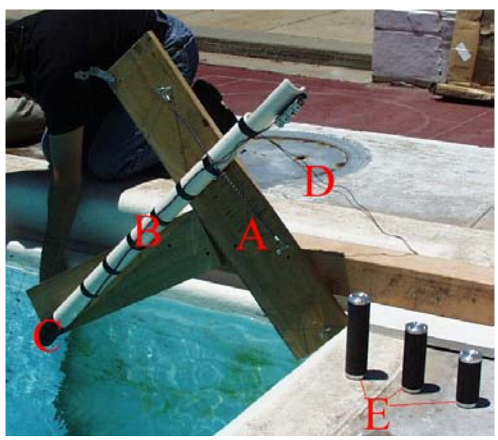

Figure 2. Equipment used. A denotes drop angle device, B mine injector, C infrared light sensor, D output to universal counter, E mine shapes.

Three mine shapes were used for the experiment. All had a circular diameter of 4 cm, however the lengths were 15, 12 and 9 cm respectively. The bodies were constructed of rigid plastic with aluminum-capped ends. Inside each was a threaded bolt, running lengthwise across the mine, and an internal weight (Fig 3). The internal weight was used to vary the mine's COM and could be adjusted fore or aft.

Figure 3. Internal Components of Mine Shape

COM positions were denoted using 2, 1, 0, -1, -2. COM 0 cases were identical to the IMPACT 25 model's uniform density assumption (COM = CB). All other cases indicated the relative position of the COM to the CB.

Initial velocity was calculated by using the voltage return of an infrared photo detector located at the base of the mine injector. The infrared sensor produced a square wave pulse when no light was detected due to blockage caused by the mine's passage. The length of the square wave pulse was converted into time by using a universal counter. Dividing the mine's length by the universal counter's time yielded V_{init}. The mines were dropped from several positions within the injector mechanism in order to produce a range of V_{init}.

Drop angle was controlled using the drop angle device. Five screw positions marked the 15, 30, 45, 60, and 75-degree positions. The drop angles were determined from the lay of the pool walkway, which was assumed to be parallel to the water's surface. Two 10 cm grids were affixed to each pool wall. These grids were constructed out of fiberglass and were used to record the mine's position in the x, -z and -y, -z planes (Fig. 4). For each drop the mines were set to a COM position. For positive COM cases, the mines were placed into the injector so that the COM was located below the center of buoyancy. For negative cases, the COM was located above the center of buoyancy prior to release. Each video camera had a film time of approximately one hour. At the end of the day, the tapes were replayed in order to determine clarity and optimum camera position.

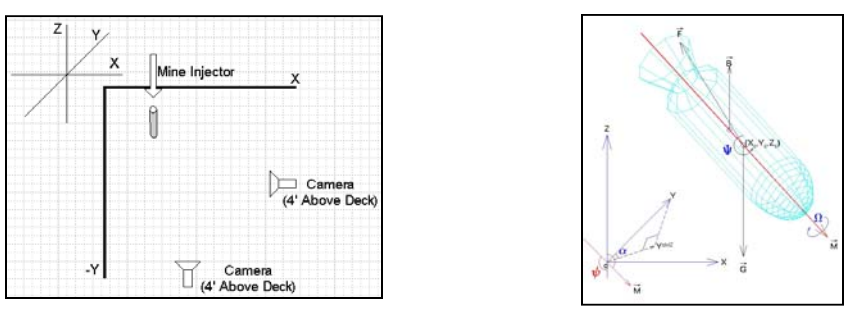

Figure 4. Earth and mine coordinate systems.

Participation of Hydrodynamic Testing of Cylindrical Mine Shape (1/3 scale) on September 10-14, 2001 at NSWC Carderock and a full size instrumented mine drop experiment on May 4-17, 2002 at Corpus Christi. Drs. Phil Valent and Mike Richardson at NRL-SSC led the experiments.

(B) Modeling Approach: We are developing a 3-D hydrodynamic model for mine movement in the water column on the base of the full physics including the balance of moment of momentum,

$$\int \left[\mathbf{r} \times \left(d\mathbf{V} / dt \right) \right] dm = \mathbf{M}_{w,a} + \mathbf{M}_b + \mathbf{M}_d \,,$$

which is absent in the current model (IMPACT25/28).

LCDR Ashely Evans (NPS student, graduating in September 2002) participated the experiment including design and data collection. LCDR Evans will analyze the data and improve the Navy's mine burial prediction model for his thesis work.

3. Mine Acoustic Detection

A more complex type of mines is influence mine. These mines have different mechanisms for activation, such as magnetic and acoustic actuators. Influence mines are much more difficult to counter since they are either tethered to the sea bottom at various depths or lie on the sea bottom. Since these types of mines are situated below the sea surface, mine hunting sonars are required for detection. The problems that are related to sonar detection of a target in the littoral are compounded when the target is a sea mine due to the low target strengths of Sea mines. The low target strengths of sea mines require the use of sensors with frequencies higher than those sonars used for submarine detection. Bottom mines create a much more difficult detection problem for the mine hunter. Operators of mine hunting systems must perform the timely process of classifying all objects that closely fit the dimensions of a Bottom mine and later evaluate these objects in closer detail with higher resolution sensors.

In recent years, the U.S. Navy has focused much of its research and development efforts in designing high frequency sensors and corresponding acoustic models to overcome the threat in the littoral. The Comprehensive Acoustic Simulation System (CASS) using the Gaussian Ray Bundle (GRAB) model is an acoustic model approved by the U.S. Navy to predict the performance of active ocean acoustic systems that operate in the 600 Hz to 100 kHz frequency range. Developed in 1993 by the Naval Undersea Warfare Center Division Newport, this model is capable of modeling all the components of passive and bistatic signal excess in range-dependent environments. The CASS/GRAB has successfully modeled torpedo acoustic performance in shallow water experiments off the coast of Southern California and Cape Cod, and is currently being developed to simulate mine warfare systems performance in the fleet (Aidala et al. 1998).

LCDR Carlos Cintron and LT Nick Vares use the CASS/GRAB model to investigate environmental effects on AN/SQQ-32 mine hunting detection and classification sonar, in particular, to determine the acoustic uncertainty in the Yellow Sea caused by the environmental uncertainty such as sea surface conditions, bathymetry, bottom type, and sound speed profiles. For example, Cintron found a strong sound channel formed that dramatically increased detection ranges at the source depth when a +1 m/s error is added to the sound profile at the source depth (Figure 5).

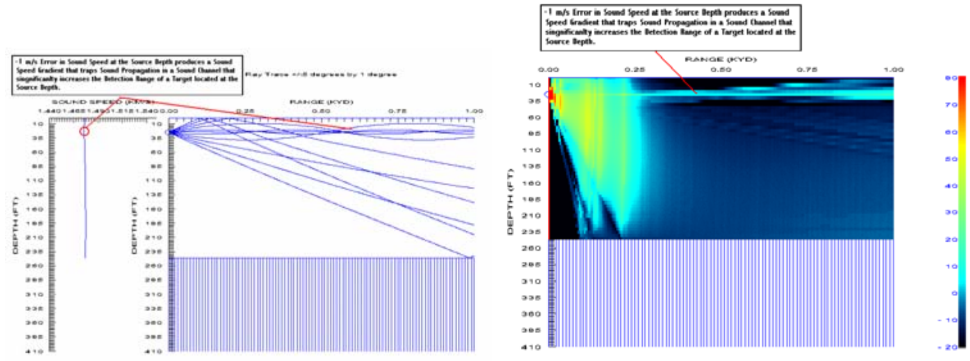

Figure 5. Effect of error (-1 m/s) added to the sound speed profile at the source depth (25 ft) for February 15, 2000, 36.4 N 124.4 E, mud bottom: (a) ray trace, (b) signal excess (maximum detection range at the source depth >1000 yd, Δ max detection range at the source depth >740 yd).

4. Oceanography for Littoral Warfare

In support of the NMOC mission and in consideration of the emphasis placed on naval operations in the littoral regions of the world, the focus of USN meteorology and oceanography (METOC) support is often on littoral regions at the mesoscale level and needs to be near-real time. One critical operating area of the USN, particularly for the 7th Fleet, is the East Asian marginal seas (EAMS). The EAMS is comprised of the South China Sea (SCS), Yellow/East China Sea (YES), and the Japan/East Sea (JES). In efforts to enhance the METOC support for this region, several NAVOCEAN-NPS theses were completed. A series of theses lead to the establishment of a Coastal Atmosphere-Ocean Coupled System (CAOCS) for the EAMS prediction. These efforts show that CAOCS is an excellent tool for USN METOC community personnel because the accurate, near-real time model output will contribute to increased meteorological, oceanographic, and acoustic forecasting skill in a littoral environment.

In his thesis, LCDR Gottashall estimated the uncertainty in the EAMS oceanographic data and models and their effect on Naval warfare simulation outcome. War games are a means to estimate the effectiveness of METOC support. War games allow participants to exercise warfighting scenarios. The objective of war gaming is to identify the major technical and war fighting issues that determine the outcome of warfare. For example, the U.S. Army used War games to model the Battle of 73 Easting, a major tank battle during the Gulf War. American tank crews tailor their tactics to the weather. A war game of this battle correctly estimates the low American casualties and suggests that using “good weather” tactics would have increased American casualties. His thesis showed the value added of exploiting the environment.

5. List of Thesis Students

Thirteen NPS students (U.S. Naval officers) completed their theses on these issues under the supervision of NPS faculty (Peter Chu) and NAVOCEANO scientists (Steven Haeger, Michael Carron, and Peter Fleischer):

(1) Fralick, Charles., "Yellow Sea thermal structure," MS in Physical Oceanography, September 1994 (co-advised by: Peter Chu and Steven Haeger).

(2) Wells, Susan K., "Temporal and spatial decorrelation scales of the Yellow Sea thermal fields," MS in Physical Oceanography, September 1994 (co-advised by: Peter Chu and Steven Haeger).

(3) Edmons, Nate, "South China Sea ocean circulations simulated by a primitive equation model," MS in Physical Oceanography, September 1996 (co-advised by Peter Chu and Steven Haeger).

(4) Veneziano, Joseph, "Hurricane Effects on the South China Sea Thermal Structure" MS in Physical Oceanography, March 1998 (co-advised by Peter Chu and Michael Carron).

(5) Taber, Vicky, "Environmental sensitivity study on mine impact burial prediction model", MS in Meteorology and Oceanography, March 1999 (co-advised by Peter Chu and Steven Haeger).

(6) Strauhs, Hilbert, "A numerical study on Japan/East Sea (JES) circulation and thermohaline structure," MS in Meteorology and Oceanography, September 1999 (co-advised by Peter Chu and Michael Carron).

(7) Smith, Timothy, "Effect of bottom shear strength on the mine burial", MS in Meteorology and Oceanography, September 2000 (co-advised by Peter Chu and Steven Haeger).

(8) Cintron, Carlos, "Environmental impact on mine hunting in the Yellow Sea using the CASS-GRAB model", MS in Physical Oceanography, March 2001 (co-advised by Peter Chu and Steven Haeger).

(9) Gilles, Anthony, "A mine drop experiment," MS in Meteorology and Oceanography, September 2001 (co-advised by Peter Chu and Peter Fleischer).

(10) Roth, Michael, "A coastal air-ocean coupled system for the East Asian Sea prediction", MS in Meteorology and Oceanography, September 2001 (co-advised by Peter Chu and Steven Haeger).

(11) Vares, Nick, "Effect of environmental uncertainty in the Yellow Sea mine hunting", MS in Physical Oceanography, June 2002 (co-advised by Peter Chu and Steven Haeger).

(12) Obino, Rodrigo, "Bohai Sea thermohaline structure and circulation", MS in Physical Oceanography, June 2002 (co-advised by Peter Chu and Steven Haeger).

(13) Evans, Ashley, "Hydrodynamics of mine impact burial", MS in Meteorology and Oceanography, September 2002 (co-advised by Peter Chu and Peter Fleischer).